



Climate change, seaports, and coastal management in Brazil: An overview of the policy framework

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ABSTRACT

Seaports are exposed to a variety of coastal risks, particularly when considering the effects of climate change, due to their location in the land–sea interface. The vulnerability of seaports, besides the robustness and design of their infrastructures, is also directly related to their adaptive capacity. A policy framework plays an important role in facing the effects of climate change by virtue of planning and supporting the implementation of adaptive measures. This research aims to identify and evaluate the extent to which the climate change topic is addressed by the port planning, coastal management, and climate adaptation policies of Brazil. A policy review was carried out and the documents were evaluated based on the achievement of the Sustainable Development Goal 13 (climate action) targets. A multiscale analysis was performed to identify how different management levels address the topic in their planning. The results suggest that although Brazil has effectively addressed the climate issue with its Adaptation National Plan, the coastal management framework and primarily port planning both remain uncertain. The existing coastal policies for climate adaptation purposes remain virtually not implemented, and accomplishments related to port adaptations are based only on a recent national sustainability guideline agenda. Although climate change impacts are perceived on a local scale, the Brazilian coastal ports and cities have not institutionalized efforts to taking climate-adaptive actions. This observed gap points out the necessity of policymakers to enhance the planning and application of adaptation measures at the local level, as well as promote the cooperation between multiscale sectoral agencies. This overview illustrates several opportunities to update, redesign, and innovate coastal and port management instruments to address climate-related issues. Nature-based Solutions would appear as a fundamental approach to be incorporated in multi-scale policy frameworks, which would support coastal ports and cities in their becoming climate-resilient, thus containing socio-economic losses and environmental deterioration.

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1. Introduction

Located in the interface between sea and land, seaports are naturally, continuously, and highly exposed to risks associated with climatic and oceanographic factors (Becker et al., 2013; Brooks and Faust, 2018). Climate change impacts challenge policy and decision-makers to incorporate the issue into the policy adaptation framework. The increased risk of coastal flooding and temporary inundations due to increases in global mean sea-levels (MSL) and extreme events such as tropical cyclones are major sources of economic losses for coastal territories and seaports (Balica et al., 2012; Becker et al., 2012; Hanson and Nicholls, 2020).

Approximately 130 ports are hit by tropical cyclones every year along coastal areas around the globe, resulting in a substantial amount of economic damage to this sector and the dependent logistic chain (Becker et al., 2012). Meanwhile, climate change is expected to intensify extreme events all over the globe. The list of impacts for seaports and the maritime shipping industry related to marine hazards and extreme meteorological events are numerous, among which intensified rainfall causes delays in loading/unloading of cargo at ports. Increased storminess can also force port canal interruption, adding risks to navigation and dock maneuvers, which poses risks to both marine and land environments and worker's safety, with subsequent economic losses (Brooks and Faust, 2018; Izaguirre et al., 2021).

As sea levels rise, port facilities might be made inoperable by flooding of piers, storage areas and breakwaters jetties, increasing costs due to relocation and/or repair of flooded facilities.

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Changes in sedimentary balance and siltation due to excessive precipitation and highly energetic sea waves also directly impact seaports, which create the need for further dredging works – and consequently costs encumber port authorities to re-establish navigation depths (Becker et al., 2012).

The last Intergovernmental Panel on Climate Change (IPCC, 2021) report stated that the recent changes in the climate system are unprecedented over thousands of years and those changes are related to increased occurrence of extreme events such as tropical cyclones, heavy precipitation and, therefore, flooding events. Regardless of the climate scenario, climate change will cause the global MSL to rise over the 21st century as well as further intensify the global water cycle.

Due to the catastrophic consequences that can be incurred in this sector, the climate change topic is gradually earning space on the global agendas of seaports. The climate change topic is currently classified as one of the top three priorities to be faced by port authorities and port systems (ESPO, 2019; WPSR, 2020). The potential economic losses associated with damage and disruption to ports around the world due to sea-level rise are estimated at between US\$ 111.6 billion by 2050 and US\$ 367.2 billion by the end of the century (UN, 2017). The negative economic impacts become even more prominent in developing countries, due to limited access to financial resources for adaptation (Becker et al., 2012; Burkett and Davidson, 2013; Brooks and Faust, 2018). This uncertain scenario may also increase future costs for global maritime transport due to the demand for resilient port facilities and safer navigation routes, breaking with traditional supply chains (Becker et al., 2012).

This complex scenario requires a legal and policy framework that will enable the implementation of integrated and adaptive measures. Several studies worldwide have been discussing and emphasizing the application of climate and coastal policies and measures for the adaptation of seaports (Oswald, 2009; Becker et al., 2012; Eisenack et al., 2012; Brooks and Faust, 2018; Hanson and Nicholls, 2020; Izaguirre et al., 2021). In this context, Nature-based Solutions – NbS (Kabisch et al., 2016; Chausson et al., 2020) emerges as an important initiative that could be incorporated into the coastal and port policies to reduce disasters and climate risk. The benefits delivered from key-ecosystem services, such as coastal protection provided by dunes, mangroves, and coral reefs surrounding port areas, for instance, can avoid or minimize negative impacts from storm surges, sea-level rise and coastal flooding on port facilities and operations (PIANC, 2014).

The Brazilian government has published a report indicating the main effects of climate hazards on coasts and several economic sectors, including seaports, and the potential responses and needs to face climate change and its impacts (Galvão and Costa Braga, 2015). The report indicates the cost of the seaports adaptation between 2030 and 2050 is around US\$ 1.3 billion, including the recommendation on improving drainage systems and building coastal defenses, such as storm surges barriers. But also indicates the opportunity and low cost of implementation of NbS measures around port areas, especially focused on mangrove management. Meanwhile, a climate risk assessment of seaports was recently launched by the National Agency of Waterway Transportation – ANTAQ (2021a,b). The report demonstrates that from the 21 Brazilian coastal ports assessed, 11 could be classified under high or very risks of sea-level rise until 2030. Nevertheless, in Brazil, there is no specific study approaching the policy framework interconnection between ports, climate, and coastal zones.

The present research aims to answer: how are the Brazilian coast and ports prepared – in terms of policy, agenda, and regulations – to face climate change? By analyzing the multi-scale policies, how is the climate issue addressed by the seaport,

coastal, and climate framework in Brazil? Which are the gaps in Brazilian port policy for dealing with the threats posed by climate change?

Our research involved a policy survey connecting multi-scale administration responses to face climate challenges from the perspective of adaptive capacity related to Integrated Coastal Zone Management, Port Planning, and Climate Adaptation. The study focal point was based on the exploratory analysis of public policies in Brazil, in which we assess the encompassing climate issue in the management framework regarding the achievement of Sustainable Development Goal 13 (UN, 2016).

It is important to highlight that this paper does not analyze the exposure and risks associated with seaports and coastal communities. The research is focused on the analysis and diagnostic development of adaptive capacity (IPCC, 2017) in terms of the ability of the government institutions and policies applied to climate adaptation, coast, and ports to respond to consequences and to take advantage of opportunities. We understand that estimating the reach of climate adaptation policies in a multi-scale and sectoral approach may not capture the public administration details, but these outcomes provide a benchmark for further research and decision-making. The legal framework evaluation could reinforce seaports' decision-making processes and define scenarios to face climate change effects while identifying gaps in the current design of the management tools.

The present article is structured as follows: in Section 2, the case study is contextualized in the scope of its port activities and climate challenges. In Section 3, the methodological steps for the multiscale analysis of policy in Brazil is presented. In Section 4, the results from the survey are presented. Then, in Section 5 we attempt to build a coastal, port, and climate adaptation policy framework overview in Brazil, highlighting the policy integration opportunities, and potential solutions to be employed. The outcomes from the survey are grouped in two distinct categories: management scales and sectoral topics covered. Lastly, in Section 6, we present the main findings and highlight future research opportunities.

2. Case study

The Santa Catarina State in southern Brazil was selected as a case study by its representativeness and importance to national port logistics, as well as its historical climate impacts both on the coastal zone and port facilities. The study area has two important Port Complexes including public and private terminals (Fig. 1): the São Francisco do Sul Port Complex, including Port of São Francisco do Sul (classified as 9th in the national public ports ranking), Port of Itapoá (4th in containership ports national ranking), and Maritime Terminal of São Francisco do Sul – an inland and offshore oil bunker facility (9th in the bunker ports national ranking); and the Itajaí Port Complex include Port of Itajaí (7th in containership ports national ranking), and Port of Navegantes (3rd in containership national ranking). In addition, there is the Port of Imbituba (13th in the national public ports national ranking), and the Port of Laguna as a fishing terminal. In the first semester of 2021, the Santa Catarina ports reached 5.4% in the general national cargo handling, increasing 34% of its operations (ANTAQ, 2021b).

The set of ports are located in important estuaries (Babitonga Bay – Northern Santa Catarina State), embayments, and headlands which act as shelter areas for docking and navigation. In addition, two ports are located at the border of the Itajaí-Açu River, near the river mouth, and although they are considered semi-protected environments – with jetties to minimize the impacts from storm surges – they are also exposed to several effects of climate change. The Port of Itajaí is especially exposed as its

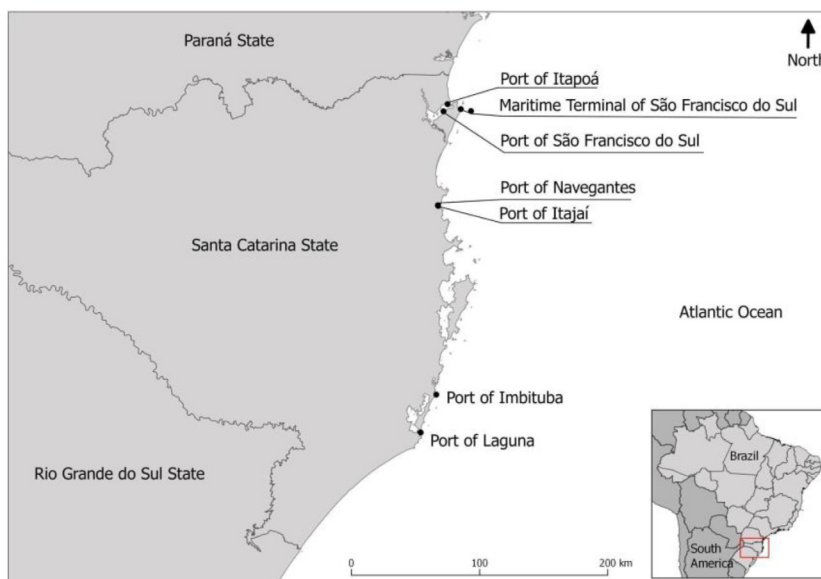


Fig. 1. Location of seaports of Santa Catarina state.

border receives more energy from the river currents than the Port of Navegantes, located on the opposite border.

Santa Catarina state is historically recognized as one of the most affected regions in Brazil by extreme meteorological events, which has caused disruptions to the local economy and human well-being (Herrmann, 2006; CEPED, 2013; de Souza and Ramos da Silva, 2021). The most well-known event is the occurrence of Hurricane Catarina in 2004, the first registered hurricane in the South Atlantic Ocean (Pezza and Simmonds, 2005). Other important climate events occurred at the Itajaí Valley in 2008 and 2011, such as rainstorms, causing the Itajaí river level to rise, and creating strong river currents (directly affecting port operations and vessel maneuvers), as well as massive floods and coastal erosion. Both events have affected millions of people and cost approximately US\$ 2 billions in losses (World Bank, 2012, 2016). Besides the physical impacts, the Port of Itajaí has experienced several operational disruptions.

The Santa Catarina region's coast is located in a cyclogenesis hotspot for the South Atlantic, *i.e.*, in a zone prone to cyclone formation (Sinclair, 1995; Hoskins and Hodges, 2005; Reboita et al., 2018; Gramcianinov et al., 2019; de Souza and Ramos da Silva, 2021; de Souza et al., 2022). The occurrence of cyclonic systems in this area is related to sea restlessness, intense wind speed, and coastal flooding on Santa Catarina's coast. It is expected for Southern Brazil a future increase in the mean summer precipitation with further increases in extreme precipitation indices (Marengo et al., 2010; Chou et al., 2014; Cabré et al., 2016). The consequence is that precipitation is expected to occur more sporadically but in higher volume, which might trigger flooding events.

Thus, given the logistics and economic importance of seaports and their exposure to risks from climate change, it is urgent that the management responses guarantee that the ports sector is covered by public policies and regulations. They must aim for prevention strategies, minimization of impacts, and especially, adaptation measures.

3. Methodology

The methodology used in this study is shown in Fig. 2.

3.1. Multiscale policy survey

The multiscale policy survey was adopted to better understand how coastal and port administration levels are facing climate change challenges. Numerous studies in Brazil, as well as in Santa Catarina State have analyzed the scope of integrated coastal zone management policies considering different government levels (Andrade and Scherer, 2014; Scherer et al., 2018; de Lima et al., 2019; Scherer and Asmus, 2021).

Firstly, we compiled policies in four distinct levels of management: national (Brazil), state (Santa Catarina), municipal (port cities in Santa Catarina state), and local (port authorities). A similar approach was carried out by Sánchez-Quinto et al. (2020) which analyzed the drives, pressures, and responses over a coastal sector in the Mexican Caribbean. The authors developed a policy assessment linking coastal and marine conservation policies with urban and climate normative framework.

A multiscale survey was carried out identifying the governmental institutions and sectoral agencies responsible for implementing public policies and programs. Then, a thorough review was developed covering public policies, plans, programs, strategies, and institutionalized good practices addressing ports, climate adaptation, and coastal management.

3.2. Policy assessment and evaluation criteria

The methodology step 2 consists of a policy framework analysis, which includes the evaluation criteria definition and policies assessment. This analysis was based on the degree to which the surveyed documents matched the targets of Sustainable Development Goal (SDG) 13: "Take urgent action to combat climate change and its impacts" (UN, 2016) as Brazil is one of the signatory countries (IPEA, 2018). Considering that the SDG is broad and general for the purpose of the research, we adapted all SDG 13 targets for the context of climate change adaptation for ports and coasts (Table 1). Then, the documents were read and evaluated to identify principles, directives, and goals in both general and specific guidelines, actions, outcomes, and indicators in prepositive sections concerning climate change adaptation.

The encompassment of the SDG 13 in the surveyed documents was examined by the identification of direct and indirect occurrence indicators. For this analysis, we searched in the surveyed

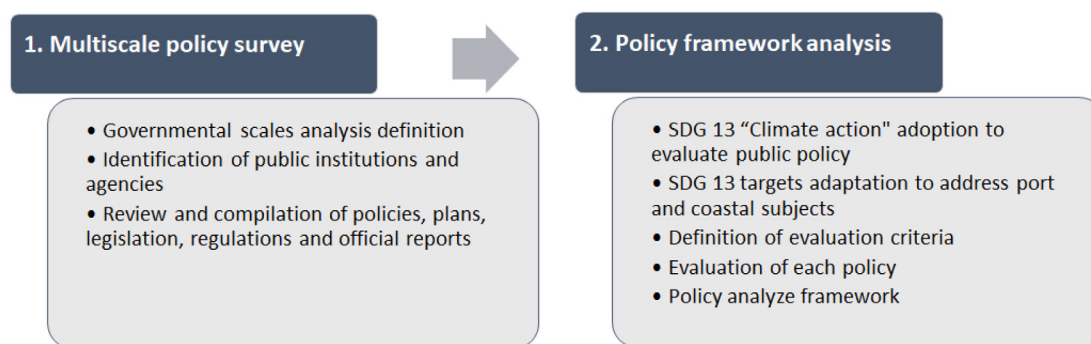


Fig. 2. Methodological steps framework.

Table 1

Adaptation of targets from the United Nations Sustainable Development Goal 13 – Climate action – for the evaluation of port and coastal sector policies.

SDG 13 – Targets	Targets adapted to the study case – seaports, and coasts
Target 13.1. Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries	The document analyzed defines actions and strategies to strengthen the adaptive capacity and resilience of logistics and port facilities, linked to climate risks.
Target 13.2. Integrate climate change measures into national policies, strategies and planning	The document analyzed promotes the inclusion of adaptation measures with coastal and port planning.
Target 13.3. Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning.	The document analyzed promotes actions and measures to improve education and training of human resources capacity on the risks to ports and coasts arising from the changing climate.
Target 13.3A. Implement the commitment undertaken by developed-country parties to the United Nations Framework Convention on Climate Change to a goal of mobilizing jointly US\$ 100 billion annually by 2020 from all sources to address the needs of developing countries in the context of meaningful mitigation actions and transparency on implementation and fully operationalize the Green Climate Fund through its capitalization as soon as possible.	The document analyzed promotes the allocation of financial resources for the climate adaptation of ports and coasts.
Target 13.3B. Promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries and small island developing States, including focusing on women, youth and local and marginalized communities.	The document analyzed promotes mechanisms to improve the adaptive capacity of port planning and coastal management.

documents the following keywords: port, port sector/activity, climate change, climate, adaptation, and adaptive management. After this, we performed a quantitative evaluation of each document surveyed. For this evaluation, a value of significance was established indicating the degree to which each of them matched the SDG 13 targets (Table 2). The proposed evaluation criteria were then separated into five distinct categories, ranging from not addressing the criteria of the policy to addressing most or all of the criteria. A similar methodology was adopted by Sánchez-Quinto et al. (2020) who assessed a group of indicators to evaluate the legal framework connecting climate and sustainable management of marine and coastal areas.

Such an approach enabled us to identify which policy is capable of responding to pressures and challenges associated with the climate change in the coastal zone and a strategic sector of the country’s economy and logistics. Moreover, this approach links to global priority actions for sustainable development at a global scale.

4. Results

The multiscale analysis was performed aiming at the diagnosis and evaluation of the government’s addressing of the climate

change issue, within the scope of the ports sector and coastal management.

4.1. Legal and management framework analysis

The proposed multiscale survey returned 33 policies, which were clustered in the four administration levels (Fig. 3).

The results from each policy evaluation, in terms of the criteria proposed in Table 2, can be found in Table 3. Fig. 4 summarizes the survey quantitative results, which were categorized by each instrument/policy scale, acting area, and attributed value regarding correspondence with SDG 13.

From all documents surveyed, only three are related to planning and adaptation to climate change, two of them being from the national scale and the other from the state scale. Most of the analyzed documents (18 or 54% of the total) are part of the ports and transport sector management and policy structure, from which 12 are documents related to port management structure: Port Master Plans – PMP, Zoning and Development Port Plan – PDZ, and Port Environmental License – PEL. The PMP and PDZ are developed under the public port administration scope.

The remaining six documents are related to the ports policy, planning, and regulation: Port Logistic National Plan – PNL, National Ports Law – NPL (2013), General Plan for Port Grants

Table 2
Response options and their significance ranges, according to the SDG targets (Table 1).

Assessment criteria	Significance
The policy address 4 to 5 criteria	
The policy address 2 to 3 criteria	
The policy address 1 criteria	
The policy does not address any criteria	
The criteria does not apply to the policy	N/A

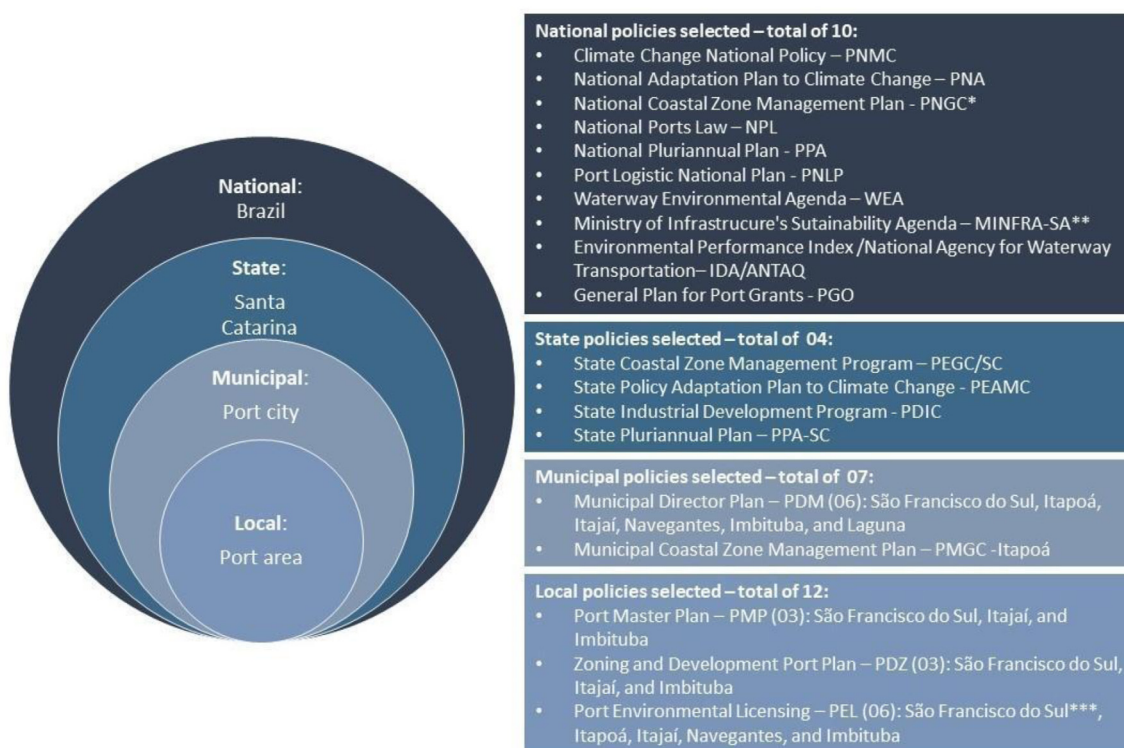


Fig. 3. The management scale and list of 33 policies analyzed and their acronyms. *The PNGC analysis included their operational instruments: ProCosta – National Program for the Shoreline Conservation, and PAF – Federal Action Plan for the coastal zone. **The MINFRA analysis included its associated document – Sustainable Guidelines for Transportation and Infrastructure. ***For the Port of São Francisco do Sul, environmental licensing was considered for the associated public and the private terminal.

– PGO (2019), Environmental Performance Index – IDA (ANTAQ, 2021b), Waterway Environmental Agenda – WEA (2018), and the Ministry of Infrastructure’s Sustainability Agenda – MINFRA-SA (2020). Nine documents (27% from the total) corresponded to the territorial and coastal planning and management topic, from which seven documents fall in the municipal scale: Director Plans – PDM, and Municipal Coastal Zone Management Plan – PMGC (2007), one in the state scale: Coastal Management State Program – PEGC (2010), and the remaining one in the federal scale: National Coastal Zone Management Plan – PNGC (2004).

We also analyzed three policy instruments (9% of the total) directed to planning, acting and climate change adaptation, two of them being at the national scale: Climate Change National Policy – PNMC (2014) and National Adaptation Plan to Climate

Change – PNA (2016) and the other at the regional scale: State Policy Adaptation Plan to Climate Change – PEAMC (2009). Lastly, three budget instruments (acting as non-binding policies) were surveyed, two of them being at the state scale: State Industrial Development Plan – PDIC (2014) and State Pluriannual Plan – PPA-SC (2017) and one at the national scale: National Pluriannual Plan – PPA (2016). In the next section, the analysis is presented regarding the acting scale and subject approach.

5. Discussion

Climate change is expected to increase pressures related to oceanographical factors due to MSL rise and higher frequency of

Table 3
Matrix of policy framework analysis and evaluation. N/A: The criteria assessed do not apply to the policy. * The policy is not available for research.

		Port city		São Francisco do Sul (SFS)	Itapoá	Navegantes	Itajaí	Imbituba	Laguna		
		Seaports		Port of SFS	Maritime Terminal of SFS	Port of Itapoá	Port of Navegantes	Port of Itajaí	Port of Imbituba	Port of Laguna	
Management analysis	Local scale	Port	Zoning and Develop. Port Plan (PDZ)	↓	N/A	N/A	N/A	↗	↓	*	
			Master Plan (PMP)	↓	N/A	N/A	N/A	↓	↓	↓	
			Environm. Licensing (PEL)	↓	↓	↓	↓	↓	↓	*	
	Munic. scale	Territorial and coastal	Director Plan (MDP)	↓		↓	↓	↓	↓	↓	
			Coastal Manag. Plan (PMGC)	N/A		↓	N/A	N/A	N/A	N/A	
	Regional scale	Climate Change	Adaptation Plan to Climate Change (PEAMC)					→			
			Territorial and coastal	Coastal Manag. Plan (PEGC)					→		
		Budget	Industrial Develop. Program (PDIC)					↓			
			Pluriannual Plan (PPA)					↗			
	Federal scale	Climate change	Climate Change National Policy (PNMC)					↗			
			National Adapt. Plan to Climate Change (PNA)					↗			
		Territorial and coastal	Coastal Manag. Plan (PNGC)					↗			
			Budget	Pluriannual Plan (PPA)					↗		
		Port	Port Logistic National Plan (PNLP)					↘			
			Waterway Environm. Agenda (WEA)					→			
			Environm. Performance Index (IDA)					↓			
			Port Law (NPL)					↓			
	Infrastr. Sustainab. Agenda (MINFRA-SA)						↗				
	General Plan for Port Grants (PGO)						↓				

extreme events (IPCC, 2021). According to a report on infrastructure in the climate scenario headed by the Brazilian Government (Galvão and Costa Braga, 2015), all the seaport facilities are exposed and at risk of climate and non-climate pressures and are classified as highly vulnerable.

Thus, the importance of identifying and understanding how nations and strategic economic sectors face and adapt to climate change seems crucial. Even at a global scale a complete assessment of risks of climate change for seaports and further planning for adaptation measures are still incipient (Hallegatte et al., 2011; Becker et al., 2012; Izaguirre et al., 2021). In Brazil, even though there are few regional high-resolution climate projections, the studies assembled by the Brazilian Panel on Climate Change (PBMC, 2014) point toward a future with more intense and frequent extreme events.

Therefore, a policy framework to respond and face such climate and oceanography challenges in the context of climatic change is mandatory to maritime transport sustainability and human well-being. In the next topics, we discuss and analyze the policy framework in terms of management scales and policy subject approach, in order to build a port and coastal climate change adaptation management panorama of Brazil.

5.1. Management scales

The performance between different management scales is substantial. The main efforts (highest scores in the policy framework analysis) are concentrated on the national scale. From the 10 documents surveyed at national scale, five presented the maximum

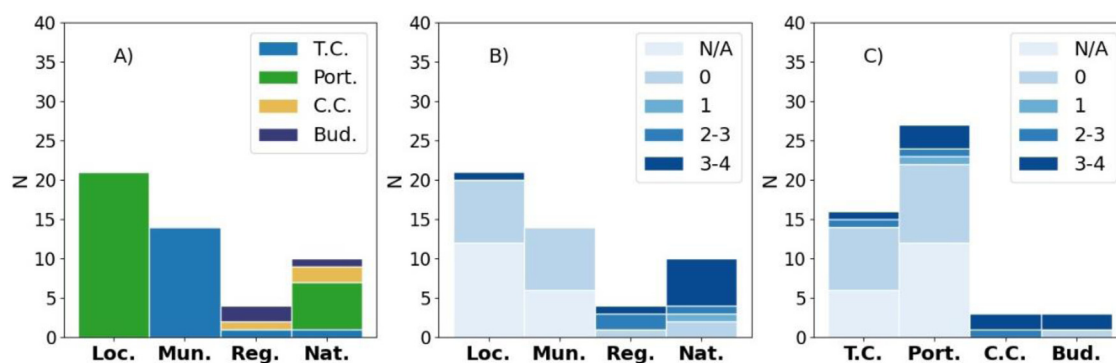


Fig. 4. The number of policies surveyed (N), grouped in distinct evaluation criteria. (A) Grouping by scale (Local, Municipal, State, and National, respectively) and theme: Territorial and Coastal (T.C.), Port, Climate Change (C.C.), and Budget (Bud). (B) Grouping by scale and scores (Table 3). (C) Grouping by subject and scores.

score based on the evaluation criteria – two related to the climate topic, PNMC and PNA, one related to the maritime transport – MINFRA-SA, one related to the coastal planning – PNGC, and one related to budget issues – PPA.

The Brazilian climate change subject is under the PNMC (2009), which includes both mitigation and adaptation measures, combined with the PNA (2016) as the main tool of the national climate policy. The PNA emerges as the main national instrument to engage and encourage sectoral activities to address goals and strategies taking into account the climate effects. PNA brings climate change adaptation goals and guidelines to be addressed and translated to regional and local levels, as well as to sectoral activities. The efforts approach 11 themes, including infrastructures and the coastal zone. In both areas, the PNA goals work toward the identification of the main risks, vulnerabilities, and impacts over coasts and infrastructures, and build climate resilience guidelines to face those challenges. Thus, current and available policies and plans from multiple management levels and sectors should be able to materialize the PNA goals.

At the state management level, besides Santa Catarina have a State Climate Change policy – PEAMC, there are no indications of adaptation measures and actions, only regarding climate mitigation. The budget instrument – PPA-SC obtained the maximum score, by indicating funding for better climate monitoring (extreme events) and efforts toward climate-proofing ports. While the PDIC, which promotes State industrial development, did not address any established criteria. For the coastal management and climate change topics (PEGC and PEAMC, respectively), the instruments at state scale contemplated between two and three criteria. Both state policies work with broad subjects not guiding any explicit action relating to or including the port activity.

The evaluation highlights extremely institutional fragility regarding the climate change topic at the local level. There is a complete absence of policies, instruments, and actions that recognize this issue and promote adaptive measures for port and territory infrastructure. Among all 19 documents surveyed at this scale, the PDZ of the Port of Itajaí was the only one that contained explicit and ongoing actions and guidelines regarding planning and adaptation to climate change. The mentioned actions refer to a pilot program developed on the scope of the Project on “Climate Services Expansion for Investments in Infrastructure”, a result of the cooperation between distinct national and foreign agencies (MMA, 2020). Their efforts are focused on providing data for port planning, aiming for short and medium-term decision-making regarding the occurrence of extreme events.

The findings highlight that most port cities and port authorities do not explicitly consider the climate risks. Becker et al. (2012) conduct research that demonstrates a low perception of climate effects over port facilities and operations. Other reasons

could be addressed by the fact that it is not always clear who is responsible for a port’s resilience. Port Authorities can wait for national financial support to develop the port’s climate resilience, especially regarding defense works, meanwhile usually private terminals have more difficulty getting financing for issues related to climate. Besides the limited resources, the low priority of the climate issue on the local agendas could explain the lack of policies and necessary implemented adaptation measures.

5.2. Policy analysis by subject approach

Amongst the land use planning and marine and coastal management policies, only the National Coastal Zone Management Plan (2004) achieved the maximum score through their operational instruments: ProCosta (MMA, 2018) and PAF (2017), both establish guidelines for climate change monitoring and adaptation on the Brazilian coastline. Although, only the PAF has been implemented. Their goals and actions regarding climate risks and port sustainability are basically focused on: the inclusion of climate lengths in the coastal management system; and the promotion of these topics in the form of training and capacitation of human resources. Meanwhile, the ProCosta program, as one of the PAF planned actions, has not been implemented by the federal government. Although, its potential to monitor and predict the climate change effects on the coastline would generate useful data for seaports and coastal communities’ adaptation alternatives decision-making.

Other coastal and territory instruments (State and Municipal Coastal Management Plan, and urban Director Plans) assessed presented few or no indications of addressing climate-related issues. No Urban Director Plan addressed climate actions. Also, Municipal Coastal Management Plans, like other coastal management tools are not often developed and implemented in Brazil (Scherer and Asmus, 2021). One exception was found – the Itapoá Coastal Management Plan – PMGC (2007), however, it does not encompass any climate change action.

Consequently, there are clear opportunities to update and include climate issues in the territorial and coastal local plans. Guidelines indicate, for instance, the necessity of the creation of buffer zones or non-building zones (which would help to decrease the exposure and vulnerability of coastal communities). Coastal ecosystem restoration provides conditions for mangroves, marine ecosystems, or dune-fields to generate ecosystem services, such as coastal protection, and sediment regulation, which benefit the entire coastline from the impacts of storm surges and coastal flooding (van der Meulen et al., 2015; Sánchez-Quinto et al., 2020).

From the budget tools perspective, the findings highlight which climate change topic figures on the prioritization list on

both national and state management levels. The Government Pluriannual Plans (PPA) are defined every four years and indicate, as non-binding policies, where the financial resources are to be allocated. The PPA advertise financial support to develop actions and strategies for the decrease of greenhouse gas emissions; training and capacitation to address climate issues on government agendas; and monitoring and data provision. Although the results are favorable in their assessment, the budgets plans have no indication of resource application on adaptation measures. Relevant measures should target coastal defense works (e.g. [Burkett and Davidson, 2013](#)) port infrastructure maintenance and improvements (e.g. [Becker et al., 2012](#)), or even for the surrounding port areas, such as ecosystem restoration (e.g. [van der Meulen et al., 2015](#)). A review on adaptation challenges targeting the risks to climate change for seaports was carried out by [Becker et al. \(2013\)](#), [Nurse-Bray et al. \(2013\)](#), and [Eisenack et al. \(2012\)](#).

Despite the high exposure of seaports, the findings show that the policy framework directly associated with port activity does not correspond at the same pace and intensity to the potential and current climate effects over port logistics and facilities. As for port management, strategies, initiatives, and guidelines regarding the climate change topic can be found in four instruments (out of a total of 17 port instruments assessed). None of the port environmental licenses (PEL) assessed indicated the inclusion of climate aspects in their mandatory environmental management requirements.

It is important to highlight that this scenario is corroborated by the absence of climate adaptation indicators from the Environmental Performance Index (IDA/ANTAQ) as the main instrument to assess environmental port performance. Although the Santa Catarina ports have among the best IDA ranking for public and private ports – Itajaí in 1st, Itapoá 2nd and Navegantes 3rd – ([ANTAQ, 2021b](#)), it is not necessarily expressed based on efforts toward climate adaptation.

On the other hand, the agendas bound to the federal government that integrate the Ministry of Infrastructure actions and tools – the Waterway Environmental Agenda (WEA) – and the Infrastructure Sustainability Agenda (MINFRA-SA) have addressed two and four criteria, respectively. The MINFRA-SA appears as important a guideline to institutionalize the climate change topic for the entire transport agenda, and as good practices to minimize climate risks. The sustainability agenda plays an important role in the entire transport planning process by promoting adaptation strategies for different types of transport in Brazil. These aspects must be incorporated in national scale planning and implemented by the port authorities.

The main federal instrument regarding port planning (PNLP) only briefly covers the climate change topic, addressing only one of the established criteria. The PNLN indicates as one of the planned actions an elaboration of the Port Adaptation and Mitigation National Plan, which should be developed in five years (deadline expired in 2020). As a top-down policy which will support and guide port authorities in local actions, the PNLN update can add some important actions and strategies for building adaptive capacity to prevent impacts on the whole maritime Brazilian logistic chain and minimize the deterioration and risks of seaports. Additionally, such guidelines promote a better connection and support between port authorities and research institutions to monitor local climate and oceanography conditions, as well to plan general adaptive measures.

Combined with the PNLN, the PGO, which also works on macro guidelines, has the opportunity to incorporate climate change adaptation principles and demands to port expansion projects or grant concessions for building new terminals. For instance, certain improvements could be based on building more resilient port access and infrastructure, such as adding climate-proofing

principles ([MMA, 2020](#)); maintaining and preserving the coastal ecosystem around the port; providing key ecosystem services that would benefit directly and indirectly port activities such as mangroves and their capacity to regulate and prevent coastal erosion and flooding as well as mitigate climate change by capturing greenhouse gases ([PIANC, 2014](#)).

Such nature-based approaches support adaptive building capacity, considering they are effective tools to address climate change and ecosystem loss as a cost-effective measure. Integrating NbS into policies, governments, and port authorities can help comply with their green commitments and to achieve SDGs, enhancing the sustainability agenda. NbS work as an umbrella for other similar approaches such as Building with Nature – BwN ([van der Meulen et al., 2015](#)), Ecosystem-based Adaptation – EbA ([Senhoury et al., 2016](#)), and Working with Nature – WwN ([PIANC, 2014](#)). Those initiatives are encouraged by the PNA, which follows EbA principles in guidelines ([MMA, 2016](#)). The EbA and NbS approach are also enhanced by the official report titled “Brasil 2040”, designed by the Brazilian government, which developed a large climate diagnostic relative to the national infrastructure and indicates potential solutions and the costs for the challenges identified ([Galvão and Costa Braga, 2015](#)). Both policies recommend the application of NbS to minimize coastal impacts from extreme events related to climate change on seaports and coastal areas.

Good practices applying green and blue infrastructures harness nature’s benefits to support coastal sustainability and create resilient infrastructures ([Kazmierczak and Carter, 2010](#)). [PIANC \(2014\)](#) has been developing assessments and discussions regarding opportunities to apply the concept of WwN by using the benefits of ecosystem services to the Waterborne Transport Infrastructure. The Port of Rotterdam (Netherlands), the main European port, which historically has faced impacts from sea-level rise and flooding, has been applying NbS and BwN measures on port expansion works ([van der Meulen et al., 2015](#)). The necessity to deepen the port canal and build drain systems using natural environmental works toward port safety and sustainability, promoting safer areas and activities, such as navigation, cargo handling, dock, and storage areas. The use of dredged sediment from the port canal to create recreational and conservation areas consists of co-benefits associated with the NbS approach. The building of new coastal lands and ecosystems also promotes cultural ecosystem services, such as tourism and recreation in the region as well as supports conservation practices ([van der Meulen et al., 2015](#)).

These examples suggest that the set of coastal ports can work as places of innovation, promotion, and opportunity to the application of solutions for facing climate challenges by generating benefits to coastal zones and communities through ecosystem services maintenance and delivery, as well as increase port operational efficiency. Nonetheless, this scenario necessarily demands political will and comprehensive change in the management and infrastructure systems.

6. Conclusion

Seaports are by their nature exposed to climate risks. The observed intensification of weather and oceanographic events results in an exponential rise of economic and logistic impacts on coastal ports and cities. These facts highlight the urgency of addressing climate issues to policymaking and adaptive measures. Nevertheless, the findings from the policy framework analysis show a large road to be ridden by the Brazilian government, local administration, and especially port authorities.

The survey conducted by this study attempted to present an assessment of Brazilian policies regarding the incorporation of climate change risks and adaptive measures within the coastal and

seaports framework. The study resulted in a political-institutional diagnostic on the different levels of the government management's capacity to make seaports and coastal cities more resilient and adapted to the climate projections. Using the SDG 13 targets as a metric in the analysis made the proposed evaluation more consistent, as the SDG constitutes an international accord signed by hundreds of nations, including Brazil, aiming at sustainable development.

Our findings demonstrate that at the national level, Brazil has established a robust climate change adaptation policy, but it is still modest in terms of addressing sectoral activities. The national climate change adaptation policy framework often has little incentive to include and prepare seaports and coastal zone management to face climate risks. The set of port and coastal policies and strategies show that they do not follow the same pace and intensity as the impacts had on port logistics, facilities, and coastal communities. There is no integration between the port and coastal management policies, as is often the case with other territorial policies.

The federal scale, and to a lesser extent the state scale, are responsible for articulating and reconciling policies and instruments for local scale application. Thus, this policy integration and application to a local level reveal the limitations in efficiently harmonizing federal guidelines to coastal cities and seaports. This scenario is validated by the fact there is little or no evidence of actions and strategies addressed by Brazilian port authorities and by port municipalities. Generally, both coastal ports and cities are reluctant to anticipate actions related to the climate issue due to uncertainty regarding the overload of their infrastructure and the high costs of financing adaptation.

Conversely, there are several opportunities for the assessed port policies and tools to update their goals and strategies in order to encourage the entire port system to become climate-resilient. Choices of new lands for expanding or building new port terminals demand federal grants and licensing to allow the port location. The PGO (budget tool) could enforce port projects (green-fields) on coastal areas with less-exposure, and the environmental licensing could require climate-proofing principles. Such as planning and development of specific adaptive measures, monitoring and data provision, human resources (port staff), education and training, as well Nature-based Solutions. Integrating Nbs into PGO and other national policies, governments can also help comply with their green commitments and to achieve SDGs.

Furthermore, we identified the PDZ and the Master Plans as the main instruments that promote port adaptation, provided that they define expansion tendencies at medium and long-range as priorities for mitigation actions and port infrastructure adaptation. Nonetheless, the study case carried out indicated that the PDZ is the only one actually being implemented with climate change protocols. The potential Master Plans update (usually defined in five years) includes opportunities to incorporate climate change adaptation strategies taking into account climate effects on port logistics and facilities.

In terms of continuous assessment, we highlight that it might be appropriate for the environmental performance index – IDA/ ANTAQ to combine new indicators to evaluate the efforts by port authorities regarding the climate issue, taking into account that the IDA tool plays an important role in the environmental assessment and management of public and private ports in Brazil.

As for policy integration, there are significant national instruments in the available framework able to cooperate in common goals. However, their implementation depends on political will and on the articulation between the involved players (Scherer and Asmus, 2021). Such actions are associated with the Port Logistic National Plan – PNLN, the Coastal Management National Plan – PNCG (and its instruments, the National Program for Shoreline

Conservation – ProCosta, Federal Action Plan for coastal zone – PAF and Coastal Management State Plan – PECG) and the National Adaptation Plan to Climate Change – PNA. Nevertheless, it is demonstrated that responses to climate risks still represent a gap in Brazilian territorial and sectoral management policy. Once this is identified, there is an immediate need for including this topic in port planning policies, which must also be in accordance with the coastal and land-use development plans as well as the national adaptation guidelines.

Finally, we highlight the importance of studies such as this one as they provide data that might support macro-diagnosis reports, raise awareness of the necessity for adaptive management, and support decision-making in different levels of management – urgent matters considering the current climate change scenario. We defend that this study serves as valuable orientation to guide public policy and investments in more research applied to building climate-proof ports and coastal cities. Seaports can be places of innovation and opportunity to apply solutions to face climate challenges. This goal demands a strategic shift in the social, natural, economic, and infrastructure systems, and proposes implementing a multi-level governance system.

CRedit authorship contribution statement

Francisco Arenhart da Veiga Lima: Conception and design of study, Acquisition of data, Analysis and/or interpretation of data, Writing – original draft, Writing – review & editing. **Danilo Couto de Souza:** Acquisition of data, Analysis and/or interpretation of data, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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